receivers can receive both broadcast and cable digital transmissions, or if subscribers can use set-top boxes to receive cable transmissions, consumers need not be concerned about being stranded, noting that CableLabs has patented a hybrid VSB-QAM demodulator that could be built into digital TV receivers for an incremental cost of approximately $15.

Similarly, Pacific Telesis (at 1) opposes any extension of the "Grand Alliance" DTV standards or application of any required transmission standards to new video technologies such as MMDS.

In light of all of these comments and the complicated issues surrounding compatibility with cable and other delivery media, we agree with those parties who believe that the best possible course for the Commission is to promote the resolution of these compatibility concerns by swiftly adopting the ATSC DTV Standard for terrestrial broadcast service, and then to rely on voluntary standards activities in all the affected industries to sort out the best solutions to these issues.[61]

VII. The Commission Should Not Impose Receiver Requirements

The Broadcasters (at *iii-iv*, 32) urge the Commission to adopt receiver standards as are necessary to ensure that consumers can choose equipment that matches at the receiving end the performance levels the standard promises at the transmitting end. They state that sets must receive all formats and reject interference, and must live up to the performance capabilities of the Grand Alliance prototype system, and that the Commission has the authority to impose such requirements. Island Broadcasting (at 3) urges the Commission to

[61]TelQuest (at 4-5) disagrees that the ATSC standard is suitably interoperable with other video delivery systems, and urges the Commission not to mandate a modulation scheme for terrestrial broadcast service, but let the industry develop a single modulation scheme other than VSB. The Commission should reject this suggestion. As explained by General Instrument in the passage quoted above, different modulation schemes are appropriate for different applications. The VSB modulation scheme was incorporated in the Advisory Committee's recommendation because it best met the needs for terrestrial broadcast service. There is no reason to think that "the industry" should, could or would adopt a single modulation scheme for all video delivery media.

require receiver designs that will maximize protection to adjacent NTSC channels from DTV channels.

A. The Commission Need Not Adopt an All-Format Receiver Requirement

In our initial comments, noting the significant amount of HDTV programming that broadcasters intend to provide, we stated that it would be foolhardy for any manufacturer to offer digital sets in the marketplace that go dark for any programming, much less a substantial amount of broadcast programming. Consequently, we said the Commission need not and should not impose a requirement that all digital receivers and converters receive all of the formats in the ATSC DTV Standard.

EIA/ATV (at 18-19) argues that nowhere in its final report did the Advisory Committee Technical Subgroup advocate an all-format requirement, that the FCC lacks authority to impose such a requirement, and that it is unnecessary in any event, because the marketplace will ensure a robust market for digital receivers and converters capable of receiving all DTV formats. MECA (at 11-12) similarly argues that with a transmission standard in place, a receiver standard is not required, and that market forces will ensure that receivers support all formats. They see a fundamental difference in that broadcasters specifically asked the Commission to adopt a standard, but manufacturers did not. Zenith (at 4) and Thomson (at 15) say a requirement is unnecessary, while General Instrument (at 4, fn. 2) argues that receiver requirements can and should be left to the marketplace. ATSC (at *iii*, 28) says all-format capability will be offered with or without a requirement.

Hitachi America (at 8-9) believes that the capability is essential and that all consumer electronics manufacturers will recognize this and act accordingly, but if not, the FCC may need to take steps. Tektronix (at 4) supports such a requirement, i.e., that all DTV receivers and set-top boxes be required to provide picture and sound from any of the DTV formats, arguing that it will do no harm.

ITI (at 3) urges the Commission to adopt a requirement that all DTV receivers receive, but not display, all formats. However, Intel (at 9, fn. 5) opposes a requirement that only all-format receivers be used, saying "If a computer equipped with a TV tuner were considered a receiver, which Intel believes is not the case, the Commission would be doing a great disservice to the computer user by first selecting several formats not suitable for computer display and then forcing the consumer to buy an expensive device that attempts to correct the problem."

After reviewing these comments we remain convinced that manufacturers will be amply motivated by marketplace forces to provide all-format reception capability, and that the Commission need not and should not impose such a requirement.

B. The Commission Should Not Impose Other Receiver Requirements

In addition to the Broadcasters, AFCCE (at 2) supports further requirements on ATV receivers, including minimum requirements for such characteristics as noise figures, equalizer range, and adjacent channel signal immunity, among others, so that the planning factors on which channel allotments are based will result in the best possible service to the public. MCEA (at *i*, 5) urges the Commission to avoid establishing performance standards for receivers, and MECA (at 12) says there clearly is no need for such requirements. Tektronix (at 4) argues that quality standards should be the subject of voluntary industry standards. ATSC (at *iii*, 29) says that its Implementation Subcommittee is examining the need for such requirements, and that if they are deemed necessary, it will work with the Consumer Electronics Manufacturers Association to develop such standards, but that such considerations need not and must not delay the adoption of a standard, whether such standards are voluntary or become the subject of FCC regulations. Thomson (at 15) and Zenith (at 15) take a position similar to ATSC's, except that any such standards should definitely be voluntary.

Siggraph urges the Commission to adopt progressive scan as the one acceptable method of *display*. Microsoft (at 7-8) asks the Commission to require that text and graphics *displayed* on a DTV meet the requirements for text and graphics currently in use for computers, and to incorporate a 72 Hz *display* rate, yet CICATS (at 22) says it does not want the Commission to mandate *display* standards. And Demos (at 2) (the architect of the CICATS counterproposal) urges the FCC to forbid the use of interlaced displays in all new digital television receivers. Intel (at 9) opposes all receiver requirements beyond those necessary to prevent cross-interference between equipment. PCUBE (at 4) urges the Commission not to mandate any receiver requirements or minimal hours of broadcast for any proposed video format.

All of these comments persuade us that our initial position on this issue remains correct. With respect to other aspects of the reception performance of receivers, the same marketplace forces that operate today to ensure that television manufacturers provide adequate reception performance will continue to motivate manufacturers to compete to provide high-quality receivers. If it is determined that any minimum performance levels need to be established for DTV receivers, they should be the subject of voluntary industry standards, just as they have been with the current analog system for many years. With respect to displays, we strongly urge the Commission not to impose any requirements whatsoever, a position that the computer industry has held for many years.

VIII. Rapid Adoption of the Standard Will Promote International Trade

In our initial comments we highlighted the efforts within the Advisory Committee to promote international compatibility of the standard, and stressed the benefits of promoting use of the standard around the world, concluding that the most important thing the Commission could do to facilitate international compatibility and promote export opportunities is to adopt the ATSC DTV Standard as rapidly as possible. The other comments on this topic strongly support these conclusions.

NTIA (at 1-2) explains that "[a]doption of a digital transmission standard promises to spur the American economy in terms of manufacturing, trade, technological development and international investment -- including job growth" and "will provide U.S. industry an opportunity to regain a larger share of the world's consumer electronics market." NTIA (at 2-3) also describes the growing momentum of DVB, and the likely negative impact if the U.S. government delays or forgoes adoption of the standard, saying "The Commission must act rapidly to ensure that American industry and consumers are able to fully capitalize on the years of hard work that have gone into the development of a new advanced television system. If we fail to act now, the window of opportunity may be closed by the success of competing foreign standards."

OSTP (at 1-3) calls attention to the ever-diminishing "window of opportunity" for the U.S. to define a worldwide standard, describes the threat that inaction will leave the field to DVB, and gives a powerful recitation of the global economic benefits that will flow to the U.S. by prompt adoption of the standard, but will be drawn away by foreign competitors if the Commission fails to act rapidly.

The Broadcasters (at 7), Thomson (at 16), Zenith (at 15-16), and ATSC (at *iv*, 30) all echo the view that the most important thing the Commission can do to promote international trade is to adopt the ATSC DTV Standard as swiftly as possible. Philips (at *v*, 16) sees America on the brink of relinquishing its lead to international competitors, and asks whether the U.S. will become an exporter of DTV and its spin-off technologies, or become an importer of an inferior foreign standard. Philips (at *v*-*vi*) and Thomson (at 2) stress the importance of adopting a standard for preserving and creating jobs for American workers. Citizens for HDTV (at 12) reiterates these concerns, noting that the European Commission has already issued a binding directive that a single digital transmission standard (DVB) will be used in cable and DBS, and a similar directive is expected soon for terrestrial broadcasts.

General Instrument (at 8-11) summarizes the history of the international trade aspects of the HDTV proceeding, and urges the Commission to help ensure that the standard is finalized expeditiously, promoted first throughout North America and then in South America and Asia, and supported in specific cases where DVB, although inferior to the ATSC Standard, is making crucial inroads.

Sony (at 11-12) argues powerfully that a critical issue of American leadership is at stake, and that a mandated standard is essential. Dolby (at 4) observes that a small delay can be explained, but failure to mandate a standard could soon cripple efforts to export the ATSC standard. Universal Studios (at 2) notes that by incorporating the standard in its rules, the FCC will lay the foundation for enhancing the position of U.S. program producers, and MPAA (at 8) argues that the standard will facilitate international program exchange.[62]

All of these comments demonstrate conclusively that the rapid adoption of the ATSC DTV Standard will promote international trade and improve our nation's international competitiveness, spurring economic growth and the creation and preservation of high-paying jobs for Americans.

IX. Conclusion

As these reply comments have amply shown, none of the arguments against adopting a complete standard, and none of the complaints raised against the ATSC DTV Standard in particular, and certainly not the CICATS counterproposal, nor anything else in the voluminous comments on the NPRM, provides a sound basis for changing the Commission's tentative decision to adopt the ATSC DTV Standard as the single standard for use by digital broadcast television licensees. In fact, the comments demonstrate conclusively that the

[62] A few parties to this proceeding have swallowed the mistaken notion that adopting the ATSC Standard would somehow help our foreign trading partners at the expense of Americans. For example, the American Homeowners Foundation (at 2) says that more jobs for American homeowners will be created by policies that increase the U.S. demand for computers than will be created by policies that increase demand for TVs, since more demand for the latter mostly creates jobs for workers of our trading partners. This type of strained, convoluted comment arises out of erroneous and misleading statements made by some members of the computer industry with respect to interoperability issues. The Commission's goal is not and should not be to handicap one industry against another, nor would any of the interoperability issues in this proceeding have that effect, contrary to the assertions of some. The Commission's primary purpose in this proceeding is to oversee the upgrading of free over-the-air television, and to ensure that a competitive marketplace operates to give consumers cost-effective options for accessing that service, including the option to buy a low-cost, basic TV, a more expensive top-of-the-line TV, or even a combined PC/TV product.

Accordingly, the Commission should adopt the ATSC DTV Standard for terrestrial broadcast transmission as rapidly as possible.

Respectfully submitted,

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APPENDIX A: DTV Receiver Cost Analysis

A Comparison of the ATSC Standard and the CICATS Proposal

In its comments, CICATS presents an economic analysis and a comparison of the impact on consumers of the proposed ATSC DTV Standard and its own single-format, baseline layered coding proposal. The CICATS analysis contains severely flawed cost estimates and volume projections.[1] The purpose of this paper is to develop a valid comparison that establishes a cost estimate for ATSC receivers that is based on the experience of manufacturing digital set-top converters for direct broadcast satellite service, CD-Interactive disk players and other digital consumer products. Background is given on how an FCC transmission standard will focus competition in the market, and on how various combinations of performance, features and costs are combined to form a product line. Technical elements of DTV receivers are described and cost estimates are developed and compared for four ATSC receiver models in a simple representative product line. Similar cost estimates are developed for the CICATS baseline receiver and a CICATS high-definition receiver. The impact of Moore's Law on the resulting estimates is also examined.

This analysis shows that by the time DTV broadcasts are available on a nationwide basis, the cost of an all-format SDTV-quality ATSC receiver will be the same or less than the CICATS single-format baseline receiver, and the cost of a full HDTV-quality ATSC receiver will be only marginally higher than the substantially lower performance baseline SDTV receiver advocated by CICATS. Furthermore, under the CICATS proposal, HDTV would not

[1]The August 12, 1996 Reply Comments of Thomson contain a detailed explanation of the erroneous assumptions used in the CICATS estimates for the unit price of an ATSC converter and for sales volume projections, which together lead CICATS to claim grossly overstated aggregate costs to consumers for the conversion to DTV.

be available until higher performance layers were added to the system, so consumers desiring HDTV would be burdened with the cost of *two* receiver purchases. Consequently, consumers will get higher performance for less cost under the ATSC Standard than under the CICAT layered coding approach, and the Commission should adopt nothing less than a standard that delivers full HDTV capability from day one, i.e., the ATSC DTV Standard.

An FCC Transmission Standard Focuses Competition

A broadcast transmission standard approved by the FCC ensures compatibility to both broadcasters and consumers. It eliminates the possibility of incompatible broadcasts or receivers, promotes universal service, eliminates consumer confusion and creates a level playing field that sharply focuses competition among receiver manufacturers. Since all receivers will receive and decode the same signals, manufacturers must compete on a balance of performance (i.e., picture and sound quality), features, and cost. Such intense, focused competition, which is typical of the consumer electronics industry, drives down prices very quickly, as evidenced by virtually every new consumer electronics product introduction. Television, color television, FM stereo, VCRs and CDs were all relatively expensive items at introduction, yet each rapidly became a commodity item that is an expected part of an average standard of living. A vivid example is that at the time of its introduction, a color TV sold for as much as a new Chevrolet. Today, a typical color TV sells for $399 -- not even close to the cost of a Chevrolet.

Now that we are on the verge of launching HDTV, some criticize the move to HDTV because retail price estimates of early HDTV receivers are in the $2,000 - $5,000 range. With the above industry perspective in mind, such arguments carry little weight. Moreover, as we will see, the prices that are generally cited are for *high-end* "flagship" HDTV receivers. Such estimates can be misleading, because they overlook cost-reduced designs that will also be available as part of a complete product line.

Various Combinations of Performance, Features and Cost Form A Product Line

A firmly established transmission standard does not specify receiver cost or performance parameters. Rather, as stated previously, it focuses the competition. Consumer demand generally spans a wide range of performance and cost. Consider the case of color TV, where even with a rigid analog standard, an incredible range of TV receiver products is available to the consumer -- ranging from a portable hand-held receiver with a 4" LCD screen, to the commonplace 25" screen size models (approximately $250), all the way to 60" home theater models (approximately $2,500). Competing manufacturers offer a wide range of models, organized in a carefully planned product line that packages various combinations of performance, features and cost designed to appeal to different segments of the market.

The performance and cost related aspects of defining a TV receiver product fall into two broad categories -- the display and the receive electronics. Even in today's TV receivers, the display constitutes the largest portion of product cost. In HDTV, the same will hold true throughout the foreseeable future. As far as the receive electronics are concerned, there are various levels of cost/performance tradeoffs that are applied to the circuit design that goes into a particular chassis. A product line is generally formed by matching the performance of the display and the receive electronics in a sensible way. For example, the "top-of-the-line" model will have the best display and receive electronics, while the "next best" may have the same electronics but a slightly lower performance display. In NTSC receivers, the best receive electronics might include de-ghosting circuitry, a line comb filter for color separation, and stereo sound. "Mid-line" models generally contain performance/cost compromises in both display and electronics elements, reducing the resolution of the CRT and eliminating the de-ghosting circuitry. In contrast, a "low-end" model will use every trick imaginable to reduce cost while providing a satisfactory level of performance, for example, by employing a simpler notch filter color separation circuit and providing only for monaural sound processing.

Technical Elements of Digital Television Receivers and Their Associated Costs

The same principles apply to digital television receivers for the ATSC DTV standard. Competing manufacturers will construct a product line just as they do today, by combining different display and electronics elements in a manner designed to appeal to various price segments of the market.

In digital television, the receive electronics portion that controls the set, tunes the channel, demodulates the digital signal to produce bits, and routes packets to their appropriate video, audio or data processor has very basic functionality that will have a relatively minor performance and cost variation across a product line. For purposes of this analysis, we shall assume that this is a fixed cost of $90 ($5 control microprocessor, $15 associated RAM and ROM, $20 tuner, $40 demodulator, $10 packet demultiplexer) for low-end and mid-line products, and $95 for high-end products ($5 additional RAM and ROM for various features).

The cost reduction in digital television receive electronics will largely focus on the MPEG decompression portion of the receiver. A full performance HDTV MPEG decompression processor must compute 62.2 million pixels per second and it requires 96 Mbits of fast SDRAM memory (more memory is used than strictly required because of the access speed required in an HDTV decoder). The current cost estimate for these elements is $132 ($60 for the MPEG decoder and $72 for the associated memory).[2] This specific design has no performance or cost compromises and it will be used in high-end HDTV receiver models. Lower cost products will be created by using less memory and less MPEG decoder processing power. Hitachi America has published and demonstrated some of their work in this area, in particular, showing that a special preprocessor could work with a 10 million pixels per second MPEG Main Level decoder with about 32 Mbits of memory. Our cost estimate for this level of performance is $64, roughly one-half that of a full performance decoder (the special

[2]Memory cost estimates use the current price of $12 for a 16 Mbit SDRAM with 10 nanosecond access time.

preprocessor is estimated to be about $10, while the cost for an MPEG Main Level decoder is well known to be approximately $30[3] and the memory cost is $24). Clearly, an intermediate level of cost and performance can be anticipated that combines a full 62.2 million pixels per second MPEG decompression processor with 64 Mbits of memory for a cost of $108 ($60 MPEG High Level decoder and $48 memory).

In digital television, the performance/cost tradeoffs that apply to the display and its related driver and deflection circuitry will be accomplished much as it is today, by selecting a CRT with a desired resolution, brightness and contrast specifications and designing a well matched deflection system. A high-resolution 720-line progressive scan display requires wideband 40 MHz video driver amplifiers, a premium deflection yoke and kinescope drivers, and a very accurate and stable 45 kHz deflection system, which in turn requires a separate deflection circuit and power supply. A cost estimate for these is $110 ($30 video drivers, $70 deflection circuits and power supply, and a $10 incremental cost on the deflection yoke itself). A high-resolution 1080-line interlaced display requires reduced specifications of 30 MHz video driver amplifiers and a 32 kHz deflection system, as well as a slight reduction in deflection yoke and kinescope drivers, resulting in a cost estimate of $82 ($25 video drivers, $50 deflection circuits and power supply, and a $7 incremental cost on the deflection yoke itself). In more cost-reduced models such as a 480-line progressive scan display, the resolution of the CRT is reduced and the bandwidth of the video drive amplifiers is correspondingly further reduced to 15 MHz, and a less costly, less precise deflection system is used that can actually employ a combined deflection and power supply circuit. In this case, the cost is reduced to $72 ($15 video drivers and $50 combined power supply and deflection system with a small fan for heat removal and a $7 incremental cost on the deflection yoke). In the case of a low-end receiver, a 480-line interlaced display might be employed with commodity 6 MHz video drivers

[3]MPEG decoder ICs are available in the marketplace at commodity prices of approximately $30.

and a conventional deflection and yoke system, resulting in a cost of $30 ($5 video drivers and $25 combined power supply and deflection system).

The remaining portion of receive electronics and another opportunity for performance-cost decisions is the display format conversion circuitry that translates the transmitted picture format (i.e., that specified as part of a transmission standard) into the format of the particular display used by the receiver. In the case of a high-end receiver with a high-resolution 720-line progressive scan display, a de-interlacer is needed to "fill in" the missing lines in the event that an interlaced transmission format is received. A high-quality de-interlacer adapts its operation to the content of the picture on a pixel-by-pixel basis. If the picture is still, the pixels from the preceding picture are a perfect representation of the "missing" lines. If the picture is moving, the "missing" lines are created by averaging the lines above and below. While real de-interlacers use variations of this basic concept, the general circuitry requirement is one frame of picture memory and some relatively simple arithmetic. To de-interlace the 1920 x 1080 interlaced format, 32 Mbits of memory ($24) and some arithmetic processing ($4)[4] is required. To de-interlace only standard definition formats, the estimated cost is $2, since the frame memory is provided from excess memory not used in the MPEG decoding of the smaller size standard-definition formats, and the arithmetic circuitry can be reduced in circuit area because several operations can be performed on each pixel with an HDTV speed processor. Only a receiver with a 720-line or 1080-line progressive scan display requires a high-definition de-interlacer. Receivers with a 1080-line interlaced display or a 480-line progressive display need only to de-interlace standard-definition formats and NTSC signals. Of course, low cost receivers with a 480-line interlaced display need no de-interlacer whatsoever.

[4]The amount of computation required in a de-interlacer is a fraction of that required in an MPEG decoder.

Receiver Cost for the ATSC Standard

Combining these various elements all together to form a simple representative product line is an enlightening exercise, shown in the chart below.

ATSC Receiver Costs

	Low-End Receiver	**Mid-Line Receiver**	**High-End Receiver**	**High-End Receiver**
Display Type	480-line interlaced	480-line progressive	1080-line interlaced	720-line progressive
Control, tuner, demod, etc.	$ 90	$ 90	$ 95	$ 95
MPEG decoder and memory	$ 64	$ 108	$ 132	$ 132
Display format conversion	$ 0	$ 2*	$ 2*	$ 28**
Display electronics	$ 30	$ 72	$ 82	$ 110
TOTAL	**$ 184**	**$ 272**	**$ 311**	**$ 365**

* -- Standard-definition de-interlacer

** -- High-definition de-interlacer

A high-end receiver will likely have a 720-line progressive scan display, and the best possible receive electronics, including a full performance MPEG decoder and a high-definition de-interlacer, resulting in a cost of $365. A slightly lower-cost high-end model might utilize a 1080-line interlaced display and full performance MPEG decoder, but need only a standard-definition de-interlacer, resulting in a cost of $311.

A mid-line receiver will likely have a 480-line progressive display and a slightly cost-reduced MPEG decoder. To produce a 480-line progressive scan display, a high-definition de-interlacer is not required since each interlaced field of the 1920 x 1080 format has 540 lines (i.e., enough to fill the 480-line display). However, a standard definition de-interlacer is needed to handle both digital SDTV formats as well as analog NTSC signals. In a 480-line progressive scan receiver, an MPEG decoder with some modest cost reduction will be used. The total cost for a 480-line progressive scan receiver is thus $272.

Finally, a low-end receiver will likely use the lowest possible cost display, namely a 480-line interlaced display. In the case of an interlaced display, no de-interlacer is needed. In addition, the most cost-reduced version of the MPEG decoder will be used. The total cost for a 480-line interlaced receiver is thus $184.

After adding in the cost of the display itself and a nominal yoke assembly, this analysis indicates that retail prices for DTV receivers would be in the $1,500 to $2,500 range at product introduction.

Using the above costs to develop an estimate for a set-top converter for NTSC receivers only involves the 480-line interlaced display case, since all NTSC receivers have an interlaced input by definition. Replacing the display electronics with a simple power supply cost ($5) and NTSC interface circuitry ($5) yields a cost of $164, and a resulting retail price of $349 to $399.

One conclusion of this analysis is that HDTV will not be overpriced at market introduction. In fact, considering its performance advantages, it will probably carry a lower relative cost than technologies such as VCR and CDs did when they were first introduced.

Receiver Cost for the CICATS Proposal

For the most part, the same cost elements would apply to the receivers contemplated by CICATS. First, let us consider a Base Layer CICATS receiver with a 480-line progressive scan display. The control, tuner, demodulation and packet demultiplexing would in fact be identical to the ATSC receiver. The MPEG decoder and its associated memory are similar in cost to a cost-reduced ATSC receiver, because the CICATS receiver must decode a progressive scan standard-definition format. The formats (up to 1024 x 512), frame rates (36 and 72 Hz) and bit rates (up to the full 18.5 Mbps of the terrestrial channel) are well beyond the performance level of the commodity MPEG Main Level decoder ICs used in DSS receivers, so more expensive devices must be used. In fact, decoding a 1024 x 512 format image at 72 frames per second means that the MPEG decoder must process 37 million pixels per second and use 24 Mbits of memory. Since this level of computational performance is between a 10 million pixel per second Main Level decoder ($30 cost estimate) and a 62 million pixel per second High Level decoder ($90 cost estimate), a cost estimate of $40 can be reasonably arrived at for the MPEG decoder, while the memory cost is $18, resulting in a combined cost of $58. In the case of display format conversion, de-interlacing must be performed on NTSC signals ($2, as in the case of ATSC receivers) and in addition, because of the 72 Hz display, frame rate conversion must be performed between the 59.94 Hz NTSC signal and the 72 Hz rate of the CICATS display. This requires a 3.6 Mbit frame buffer for the NTSC signal and appropriate address control (so assume $2 for the memory cost and that the addressing is "free"). Therefore, the combined cost of display format conversion circuitry in the CICATS Base Layer receiver is $4. Display electronics would be the same as the ATSC 480-line progressive scan receiver, $72. The total cost of a CICATS Base Layer receiver adds up to be $224, as shown in the table below.

Now let us consider a CICATS HDTV receiver with a 720 line-progressive scan display. Again, the control, tuner, demodulation and packet demultiplexing would be identical to an ATSC receiver. The MPEG decoder and its associated memory are now substantially higher than an ATSC receiver, because the CICATS receiver must decode a high-definition progressive scan enhancement layer format and the base layer format as well. This means that the MPEG decoder must process 2048 x 1024 pixels at 72 Hz (150 million pixels per second) plus 1024 x 512 pixels at 72 Hz (37 million pixels per second), for a total processing rate of 187 million pixels per second. This is three times the computation required in an ATSC receiver, which we will assume can be achieved for a cost of $100 (a very optimistic estimate). In addition, the CICATS receiver must have memory for both the base layer and the enhancement layer (198 Mbits of memory) at a cost of $148. The combined MPEG decoder and memory cost in a CICATS HDTV receivers is thus estimated at $248. In the case of display format conversion, NTSC de-interlacing and frame rate conversion are needed ($4, as described above), plus an additional conversion to the 720-line display format ($1) for a combined cost of $5. Display electronics would be the same as the ATSC 720-line progressive scan receiver, $110. Thus, the total cost of a CICATS HDTV receiver adds up to be $ 458, as shown in the table below.

CICATS Receiver Costs

	Base Layer Receiver	**Full HDTV Receiver**
Display type	480-line progressive	720-line progressive
Control, tuner, demod, etc.	$ 90	$ 95
MPEG decoder and memory	$ 58	$ 248
Display format conversion	$ 4	$ 5
Display electronics	$ 72	$ 110
TOTAL	$ 224	$ 458

Receiver Cost Difference Between the ATSC Standard and CICATS Proposal

Comparing the results of the cost analyses of ATSC and CICATS receivers shows that the CICATS HDTV receiver has an electronics cost of $458, compared to a comparable ATSC receiver electronics cost of $365. The CICATS HDTV receiver thus has $93 more cost, which translates into a retail price difference of more than $200. The CICATS approach would thus impose higher costs than the ATSC standard on consumers that wish to enjoy the benefits of full HDTV performance.

The CICATS Base Layer receiver has an electronics cost of $224, compared to the electronics cost of a comparable 480-line progressive scan ATSC receiver at $272 -- a cost difference of $48). It is interesting to note that an ATSC receiver with a 480-line *interlaced* display has an electronics cost of only $184 -- i.e., $40 lower than the CICATS base layer receiver! (Of course, interlaced displays could also be used under the CICATS approach to reduce cost.)

Even while complaining of the supposed high cost of ATSC receivers, CICATS is quick to cite the impact of ever-advancing integrated circuit technology to increase performance and drive down costs. Since all of the cost estimates discussed are today's prices, let us use Moore's Law to predict the cost difference between ATSC and CICATS receivers over the time frame of DTV service introduction.

Moore's Law Quickly Makes Today's Small Cost Difference Irrelevant

Moore's Law, often cited by computer industry representatives, predicts that integrated circuit technology will advance by a factor of two every two years[5]. Applying that to the time frame for DTV introduction reinforces the conclusion that HDTV is not expensive. With FCC approval of the ATSC standard in 1996, the first DTV stations will go on the air in 1998. With up to three years to apply for a license and up to an additional three years to construct, it will be 2002 before all televisions stations are on the air with DTV. As shown in the table below, applying Moore's Law to the $48 cost difference between a 480-line progressive scan ATSC receiver and a CICATS Base Layer receiver results in a $24 cost difference at the time of market introduction, which is reduced to $3 by the year 2004.

[5]Moore's Law is often stated as a factor of two performance improvement every eighteen months (as in CICATS' technical description). We use the more conservative figure here, as CICATS did in its cost estimates.

ATSC & CICATS Base Layer Cost Difference

Year	(comparable 480-line progressive receivers)
1996 -- receiver design stage	$ 48
1998 -- first DTV stations on-air	$ 24
2002 -- all DTV stations on air	$ 6
2004 -- substantial market penetration	$ 3

The FCC Should Approve the ATSC DTV Standard

This cost analysis shows that cost-effective HDTV receivers can be produced for the ATSC DTV Standard. FCC approval of this standard will allow broadcasters to upgrade both the quantity and the technical quality of the service they provide to consumers, and will establish a level playing field for manufacturers to produce innovative, competitive products. With freedom to purchase a DTV receiver at various levels of performance and price, the consumer is the ultimate marketplace driver and beneficiary of competition.